THE RESPONSE OF UNDERSTORY OAK SEEDLINGS TO RELEASE AFTER PARTIAL CUTTING

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Summary

Fifty white, northern red and chestnut oak seedlings, formerly part of the understory of a mature oak stand, were studied for a five-year period after a single-tree selection cutting to determine what characteristics of understory oak seedlings can be used to predict their rate of height growth following removal of the overstory.

In the spring of 1963 these seedlings were evaluated for vigor (color, size and density of foliage), erectness of stem, crown conformation, total height, number of leaves, and per cent of full sunlight received, to see which of these was most closely related with total height growth over the next four growing seasons.

Crown conformation was the only factor significantly correlated with the rate of height growth after release. Both white oaks and northern red oaks with flat crowns at the time of release grew much more slowly than did those seedlings with normal crown conformation.

Flat-topped oak seedlings did respond gradually to release. Of the 32 flat-topped seedlings included in this study, 17 had established an active leader by 1966. The lesser value of flat-topped oaks as a potential nucleus for the next rotation is attributed primarily to the delay before normal height growth is attained, and the likelihood that competing woody vegetation will overtop them during the slow recovery period.

Annual photographs of each seedling from 1964 to 1966 showed that most non-erect seedlings gradually straightened and regained an upright position after release. Occasionally flat-crowned seedlings sprouted at the root collar, and the sprout overtook and outgrew the older stem. Usually, however, flat-topped seedlings recovered by establishing a new leader from a terminal bud at some point in the crown, or from dormant buds within or just below the crown.

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The Response of Understory Oak Seedlings to Release After Partial Cutting

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REPRODUCTION CUTTINGS in mixed oak types have focused attention on certain difficulties encountered in replacing mature oak stands with an adequate number of desirable, vigorous oak seedlings. Although promising mixtures of oak seedlings frequently dominate the site after mature oak is cut, it is not unusual to have species of much lower commercial value predominant in the new stand.

Since oak types comprise a large area of West Virginia's commercial forest land, and are of great importance to the State's economy because of the wide variety of wood products dependent on a continuous supply of quality oak, concern has developed for the future productivity of many sites after the present mature oaks are removed. Because of the degradation in species composition that may follow harvest, studies are in progress at the West Virginia University Agricultural Experiment Station to determine those environmental factors which contribute to adverse changes in stand composition. From this information it is hoped that systems for managing existing oak stands can be devised which will assure valuable species in the next rotation.

This bulletin summarizes a four-year study of the response to release of oak seedlings and seedling-sprouts following a single-tree selection cutting on an upland site, typical of those areas were oak is, or should be, the dominant species.

Review of Previous Work

Unless some drastic measure for eradicating the existing understory is employed at the time mature oak types are harvested, the composition of the new stand is determined primarily by the understory species present prior to the harvest cut. In other words, those species which will dominate the next rotation can be accurately predicted from the composition of the existing understory. Thus, environmental conditions which result in variations in the number of advanced-growth oak seedlings beneath mature oak stands have received much study in the initial phases of this research project.

The amount, composition, and vigor of regeneration beneath 68 mature oak stands, representing a wide range of site conditions, were described by Tryon and Carvell (1958). Great differences in the amount of oak reproduction occurred between study areas. In general, the number of oak seedlings was higher than had been anticipated, with the majority of oak seedlings less than one-foot tall. One-half of the study areas had 2,500 oak seedlings or more per acre. However, much variability was found in the amount of oak reproduction per stand, ranging from 125 to 55,750 per acre for all oak seedlings, and 85 to 41,125 when first-year oaks were excluded.

Acorn collection over a five-year period showed relatively small differences in total acorn production, number of sound acorns, and insect and animal loss, between sites with abundant and those with sparse oak reproduction (Tryon and Carvell 1962). Variations in amount of understory oak appeared to be the result of site factors acting on the acorn, or on the seedling. During the five-year period, northern red oak (*Quercus rubra* L.) produced the most mast but white oak (*Quercus alba* L.) produced the most seedlings. Most of the seedlings on the study plots were in the smallest size classes. Seedling abundance declined rapidly with increasing height. This decrease was attributed primarily to low light intensity, since taller oak seedlings require more light to survive.

A further study emphasized that the ability of oak regeneration to survive and build-up on a specific site is more closely related to environmental conditions than is the ability to become established (Carvell and Tryon 1961). Per cent sunlight reaching the forest floor showed a significant correlation with the amount of oak regeneration. Aspect was another significant factor in oak seedling survival. Dry exposures, south, southwest, and west, had far greater oak seedling survival, since on these aspects crown canopies were more open, thus more sunlight reached the understory. In addition, this study indicated that stands which had been disturbed previously by partial cutting, or had formerly been grazed or lightly burned, generally possessed a greater reservoir of oak reproduction than stands which had no history of disturbance. The greater amount of oak regeneration after such disturbances was attributed to increased amounts of understory light.

In a southeastern Ohio study, Merz and Boyce (1958) described reproduction counts made two years after cutting in an oak stand. They attributed the present distribution of oak regeneration to stand conditions existing prior to the cutting.

Walters (1963), studying the response of yellow-poplar (*Liriodendron tulipifera* L.) and oaks to release in southeastern Ohio, found that potential members of the future stand could best be identified by

evaluating seedling height, last year's height growth, and present crown position.

Bey (1964) reported that 27 years after clearcutting an oak-hickory stand in Illinois the site was completely stocked with oaks, hickory (*Carya* spp.), black walnut (*Juglans nigra* L.), and yellow-poplar. He concluded that, when desirable advanced oak reproduction was present, clearcutting resulted in a high per cent of rapidly-growing, straight-stemmed oaks.

In Connecticut, studies of advanced growth following thinnings and shelterwood cuttings, older seedlings and small saplings in the advanced reproduction which had been suppressed for many years prior to partial cutting were found to be of little value as growing stock (Leffelman and Hawley 1925). Suppressed trees were frequently dominant in the regeneration; these could be recognized by their flat tops and crooked stems. These authors recommended that such stems be removed in cleanings. However, they emphasized that it would be a mistake, both financially and silviculturally, to cut down or otherwise eliminate the advanced growth in toto. Actually, during logging, the advanced growth should be protected as much as possible.

Jensen and Wilson (1951) concluded from studies in New England northern hardwood types that the sprouts that developed after mowing American beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula alleghaniensis* Britton), and sugar maple (*Acer saccharum* Marsh.) had straighter boles, fewer whip-like stems, and better-developed, more symmetrical crowns than did the original understory. However, they concluded that gains from mowing regeneration did not seem great enough to justify the cost.

From these studies it appears that adequate advanced oak regeneration is only one factor in assuring that vigorous oak seedlings dominate the new stand. It is equally important that advanced oak seedlings are vigorous, or capable of regaining vigor quickly, so that they can compete successfully with other advanced-growth species and new seedlings appearing after cutting. Thus, a method of evaluating the potential response of advanced-growth oak beneath mature stands would be of value in identifying those stands where an adequate number of understory oak seedlings have the ability to initiate rapid height growth and thereby compete successfully with other vegetation after cutting.

Description of Study Area

The stand selected for this study was one in which understory composition, acorn production, and other environmental conditions had been studied previously (Tryon and Carvell 1958, 1962; Carvell

[1]Cutting advanced growth off at ground level

Tryon 1961). A heavy single-tree selection cutting was made in this stand during the winter of 1961-62. In this cut the mature oaks were removed. Since in some parts of the stand the mature trees were arranged in small groups, the area of crown openings created by this cut varied considerably, the maximum being approximately one-quarter acre in size.

This stand is located in Monongalia County on Chestnut Ridge, the westernmost range of the Allegheny Mountains. The study area is located on a ridge top with a 2-5 per cent slope towards the northwest. The site index for oak is 61, thus the site would be considered merely average for the growth of oak. The soil is a Dekalb clay loam. Light intensity studies prior to cutting showed that an average of 3.22 per cent of full sunlight reached the understory.

In previous studies (Tryon and Carvell 1958) this stand had been rated "above average" in amount of understory oaks. Prior to cutting, the overstory consisted of white oak, northern red oak, black oak (*Quercus velutina* Lam.), chestnut oak (*Quercus prinus* L.), red maple (*Acer rubrum* L.) and hickory. Tree seedlings in the understory, 10 feet or less in height, in order of declining abundance were: black oak, white oak, chestnut oak, red maple, sassafras (*Sassafras albidum* [Nutt.] Nees), scarlet oak (*Quercus coccinea* Muench.), northern red oak, and hickory.

Experimental Design

In the spring of 1963 fifty oak seedlings or seedling-sprouts were selected from various locations within the cutting area. Twenty-two were white oak, 24 northern red oak, and 4 chestnut oak. These seedlings varied in height, stem form, and crown condition, as reflected in erectness of stem, crown conformation, and density and color of foliage. In addition, varying degrees of release were included. Sprouts resulting from damage to seedlings or seedling-sprouts during logging were excluded from this study.

In 1963, 1965, and 1966 these seedlings were measured and evaluated to discover how rapidly they responded to release and began vigorous height growth. In recording these characteristics, crown conformation was described as flat-topped (umbrella-shaped) or normal. Flat-topped crowns were those where no definite leader could be identified, and where no part of the upper crown extended conspicuously above other upper crown foliage (Figure 1A).

Seedlings were classified as erect or not-erect. Erect seedlings were those with the leader directly above the base of the bole, or in flat-topped seedlings those where the crown appeared to be balanced around an axis perpendicular to the base of the bole (Figures 2A and 3A).

Height was measured perpendicularly from the ground to the highest point of the crown.

The light intensity immediately above the crown of the seedling was obtained in 1965 using a photo electric cell. Measurements were made at eight randomly-selected points on each crown surface. Their average was expressed as a per cent of full sunlight in the open at the same time that the measurements on the seedlings were recorded.

Vigor, a final evaluation, was obtained from an overall impression of the seedling. In judging vigor the size and color of the leaves and the density of the foliage were all considered. Vigor was rated as 1, excellent; 2, moderate; and 3, poor. The vigor of the seedling in Figure 3A was rated "moderate" and the seedling in Figure 4 was rated "poor."

In 1964, 1965, and 1966 each seedling was photographed from a fixed point to record changes that were taking place.

Analysis of Data

In analyzing these data graphs were plotted initially to discover those factors or combinations of factors which were correlated with the dependent variable, total height growth during the four-year period, 1963-1966.

Multiple regression analysis was used to determine which factors showed the strongest correlation with total height growth. A regression was selected of the form:

$$Y_t = b_0 + b_1V + b_2E + b_3U + b_4H + b_5(F/H) + b_6L$$

where:

Y_t = total height growth for the four-year period in inches.

V = seedling vigor in 1963.

E = erectness of seedling in 1963 using −1 for non-erect seedlings and +1 for erect seedlings.

U = crown conformation using −1 for flat-topped seedlings and +1 for those with normal crowns.

H = total height of the seedlings in inches in 1965.

F = number of leaves in 1963.

L = per cent sunlight received by the seedling in 1965.

$b_0, b_1, b_2, \ldots, b_6$ = numerical coefficients to be derived from the data.

The normal equations of the regression were determined and the forward solutions and mean square of the residuals obtained. The forward solution was then recalculated using the Kincer and Mattice Method (Kincer and Mattice 1928) for determining the most significant factors. In this analysis only one variable, crown conformation (U), was significant (1 per cent level).

The back solution and coefficient for the significant variable (U) were computed yielding the equation:

$$Y_4 = 27.826 + 9.138\ U$$

A similar analysis following the 1965 measurements had shown the same pattern of significance, and had yielded the regression equation:

$$Y_3 = 19.663 + 5.676\ U$$

The changes in height for the years 1962, 1963, 1965, and 1966 are presented in Figure 9. The 1964 evaluations included only photographs, thus no bar graphs could be included for that year.

A series of t-tests was used in further analysis of these results. These tests showed that four-year growth differences between flat-topped and normal seedlings were significant at the 1 per cent level.

To discover whether flat-topped-seedling growth response varied between northern red oak and white oak a t-test was used. This indicated that the white oaks (white and chestnut oaks combined) with normal crowns showed significantly greater height growth than flat-topped oaks of these species (5 per cent level). A similar t-test for northern red oak seedlings showed the same significant difference.

A t-test of four-year height growth between flat-topped white oaks and flat-topped northern red oaks showed no significant difference. Tests for the same period between white and northern red oaks with normal crown conformation also showed no significant difference.

Photographs of northern red oaks and white oaks for 1964, 1965, and 1966 are presented in Figures 1 through 8.

Discussion

Flat-topped crowns denote extremely low vigor, and the inability to initiate rapid height growth after release. This study indicates, however, that most flat-topped seedlings will eventually reestablish a leader and resume normal height growth. Thus, the lesser value of flat-topped oak seedlings is attributed primarily to the delay before normal height growth is restored, and the likelihood that competing woody vegetation will overtop them during the recovery period.

Of the 32 oak seedlings classified as flat-topped in 1963, 6 had established a leader by 1965, and 17 had established a leader by 1966. New leaders developed in various ways: some from a terminal bud at a point in the crown (see Figure 3), others from dormant buds from within or below the crown. In many cases the new leader developed from a point in the crown vertically above the stem base. When the leader developed from a point in the crown other than directly above

the stem base, that portion of the crown that assumed leadership was gradually moved into proper position above the base by straightening of the stem. Regardless of the point in the crown at which the new leader formed, it appeared that a desirable seedling with a straight, erect bole would eventually result, if competing vegetation did not overtop the oak seedling during the recovery period. A few flat-topped, non-erect seedlings regained a new leader and an erect stem within the four-year period covered by this study (Figure 1).

In a few instances flat-topped seedlings developed one or more vigorous sprouts at the root collar (Figure 1). When this happened, the new sprout developed rapidly, while the older flat-topped portion continued to increase slowly in vigor. The sprout quickly overtook the older stem. As the young stand develops and crown closure takes place, the slower-growing portion of these seedlings will be overtopped and eventually die back. Thus, in these cases the sprout will usually replace the older stem. However, only three of the flat-topped seedlings developed basal sprouts, and this form of recovery appears to be the less usual method for flat-topped oak seedlings.

After release, all flat-topped seedlings increased their number of leaves rapidly. The average number of leaves for those seedlings that remained flat-topped throughout this study increased from 78 in 1963 to 286 in 1966. This increase in photosynthetic area was accompanied by a spreading out of the crown, causing it to occupy an increasingly greater area. This expanding of flat-topped crowns results in a serious problem since each year they shade a greater area of the forest floor, and adjacent smaller seedlings are gradually overtopped and suppressed.

Flat-topped seedlings with two or more equally strong stems, the result of forking below the crown, remain lower in vigor and have more difficulty in establishing a leader than do those seedlings with a single stem (see Figure 8).

It was surprising that there was no correlation between 1963 vigor class and height growth during the four-year period. However, those oaks in vigor classes 1 and 2 combined did grow significantly more than those in vigor class 3. Although, in rating vigor, leaf size, color and foliage density were the primary criteria, it appears that crown conformation is a more reliable measure of ability to respond than the three factors used in judging vigor.

Per cent sunlight after release failed to show a significant relationship with height growth. Per cent sunlight after release varied from 59 to 89.5 per cent. Since oak seedlings are relatively shade tolerant, it appears that after the selection cutting all of the seedlings included in this study were receiving an adequate amount of light for more vigorous

growth. Graphs of these data indicated that most seedlings receiving increases to 10-20 per cent of full sunlight were growing in height as rapidly as those receiving 80-90 per cent. It is possible that high exposure to sunlight resulted in drying out of the surface soil, and that the poorly-developed root systems of these formerly overtopped seedlings were unable to obtain sufficient moisture to take advantage of the greater amount of light.

One aspect of seedling recovery, which was brought out by the photographic study, is the ability of non-erect seedlings to straighten and regain a more erect position after release. Straightening occurred at different points in the stem and within the crown. Many leaning seedlings became more erect by stem changes at the root collar (see Figures 3 and 4). Others straightened at some point along the stem, often where the branch supporting the new leader joined the main bole (see Figure 6). In addition, a noticeable straightening of crooks in the bole occurred after release. This is possibly explained by the unequal deposition of new wood around these irregularities (see Figures 1, 3, 4 and 6).

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(FIGURES)

1 through 9

FIGURE 1. (1A, 1964; 1B, 1965; 1C, 1966). In 1963 this white oak seedling was classified as flat-topped, non-erect, and of moderate vigor. After release it was receiving 86 per cent full sunlight. A leader developed in 1965, and the stem straightened during the following year.

FIGURE 2. (2A, 1964; 2B, 1965; 2C, 1966). In 1963 this red oak sapling was classified as flat-topped, erect, and of moderate vigor. After release it was receiving 15 per cent full sunlight.

FIGURE 3. (3A, 1964; 3B, 1965; 3C, 1966). In 1963 this white oak seedling was described as flat-topped, non-erect, and of moderate vigor. After release it was receiving 86 per cent full sunlight. The spectacular straightening of this seedling occurred primarily from the root collar. After a leader developed in 1965, the upper portion straightened rapidly.

FIGURE 4: (4A, 1964; 4B, 1965; 4C, 1966). In 1963 this red oak was classified as flat topped, non-erect, and of poor vigor. The sprout at the base developed in 1963, and by 1966 had nearly overtaken the older stem. In spite of the sprout's rapid development, the leaning stem continued to straighten and increase in vigor. The sprout will probably suppress the older stem within the next few years. After release this oak was receiving 19 per cent full sunlight.

FIGURE 5. (5A, 1964; 5B, 1965; 5C, 1966). In 1963 this red oak sapling was classified as non-erect, flat-topped, and of moderate vigor. One of the two branches of the upper crown became dominant in 1965, and within the next year this branch straightened at the point where it joined the main stem. After release this sapling was receiving 86 per cent full sunlight.

FIGURE 6. (6A, 1964; 6B, 1965; 6C, 1966). In 1963 this sapling was classified as flat topped, erect, and of moderate vigor. The dominant branch in 1964 moved to a vertical position by 1966, primarily through straightening at the intersection of this branch with the bole. After release this sapling was receiving 88 per cent full sunlight.

FIGURE 7. (7A, 1964; 7B, 1965; 7C, 1966). In 1963 this white oak seedling was classified as flat-topped, erect, and of moderate vigor. A moderate amount of straightening has occurred, primarily at the root collar. After release this seedling was receiving 87 per cent full sunlight.

FIGURE 8. (8A, 1964; 8B, 1965; 8C, 1966). In 1963 this red oak seedling was classified as erect, flat-topped, and of poor vigor. Seedlings with two equally strong forks originating below the crown appear to respond slowly to release. This seedling received 87 per cent full sunlight after release.

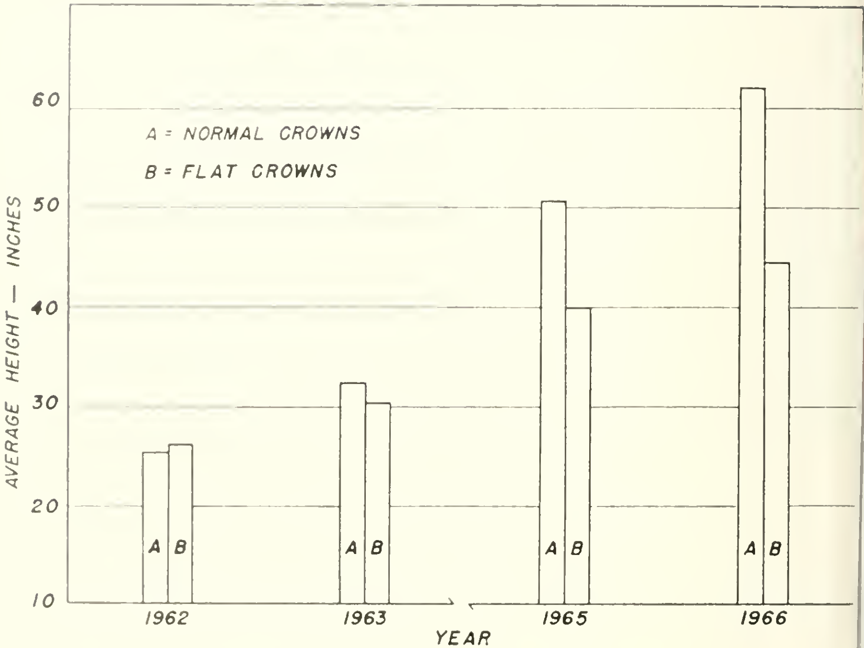

Figure 9. Average heights by years for the 50 oak seedlings included in this study. The averages for flat-topped seedlings include those so designated at the beginning of the study in the spring of 1963, and include seedlings which later developed a leader.